Chapter 3

Functions and Characteristics of All Aquaculture Systems

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Aquaculture is an extremely diverse enterprise. We work in very different environments (freshwater, brackish water, saltwater), which can represent extremely different physiological challenges to the animal being raised. We also work with many different species, some estimates exceed 400, with the number growing each year. To make things even more complicated, most of these species have not even been domesticated. How different from terrestrial livestock is it working with aquatic animals? *Very*. Here are a few examples to make a point.

3.1 Differences in aquatic and terrestrial livestock

(1) Many of the finfish we raise are carnivores. Why? Because this is what consumers want to buy. However, it creates many difficulties when it comes to formulating diets and also in terms of production systems. Chicken houses would look a lot different if the chickens were prone to *eat* each other.
(2) Many of our culture animals live suspended or swimming in the water column (termed pelagic). I don't know of any terrestrial livestock that floats or flies in mid-air. For aquaculture this can be an advantage as we can utilize all three dimensions of the culture system. However, it can also be a disadvantage in that many fishes do not readily feed at the surface or at the bottom.
(3) For some aquaculture species, the opposite is the case. The animals are completely sessile and attached to bottom (such as oysters). In terrestrial

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agriculture this is true of plants, but not the animals! Because of this, these animals are unable to avoid issues of poor water quality or move away to avoid predators. In fact, siltation can be a problem. Imagine poultry producers that had to worry about their flock being suffocated by a dust storm.

(4) Many aquacultured animals are filter feeders. Again, can you think of a terrestrial livestock species that gets its food by catching dust blowing in the wind?

(5) Most aquaculture animals are r-strategist while most terrestrial livestock are K-strategists. In simple terms r-strategist animals produce a lot of offspring but invest little care or energy into each. In contrast, K-strategists have fewer offspring with more investment in each. Fecundity and potential number of offspring are often far higher in aquatic than in terrestrial animals. A cow will produce only a maximum of two calves in a year or twenty in a lifetime; a pig maybe eight piglets per litter and fifty in a lifetime; and a chicken may lay 325 eggs per year over a maximum of eight years with a possible total of 1,800 offspring. However, a single adult female oyster can produce 20 to 30 million eggs at once (Galtsoff 1964) and the Atlantic cod (*Gadus morhua*) produces 10 million eggs (Williams 1975).

(6) For many aquaculture species the offspring are tiny! Can you picture the poor swine producer whose piglets could pass through a window screen? What and how do you feed them? Well, that is the problem that producers of marine fish and shellfish species face. Newly hatched larvae may only be 100 to 200 μm in length and require unicellular algae or rotifers (<200 μm) as their early diets.

(7) Osmoregulation. For terrestrial animals air is pretty much air but for aquatic animals freshwater and saltwater represent very different environments and physiological challenges. Virtually all aquatic animals have to work against their external environment to maintain their internal environment. Most fish require an internal osmotic concentration of 250 to 500 m Osmol/kg. However, freshwater is <0.1 m Osmol/kg and seawater is approximately 1,000 m Osmol/kg (Evans & Claiborne 2008). That means that in marine fish, water is constantly trying to leave the fish and in freshwater species, water is constantly trying to move into the fish. Some species, known as euryhaline species, have mechanisms that allow them to adapt to a range of salinities. Others known as stenohaline are strictly confined to one environment or the other.

We also raise these organisms many different ways. Production systems range from being basically natural systems with a few extra animals added and little management intervention (for example reservoir ranching, chapter 8), all the way up to super-intensive recirculating systems with the animals basically being on life support and the aquaculturist having to "play God" around the clock (see recycle systems, chapter 11). However, despite all of these differences, there are also characteristics and functions that all aquaculture systems share.

Even more than terrestrial farm animals, aquatic animals are captives of their environment. All terrestrial livestock are homeotherms (warm-blooded). That means they are able to regulate their body temperatures to stay within the

narrow range needed for proper function. However, aquacultured animals are primarily poikilothermic (cold-blooded), so their body temperature is basically the temperature of their environment.

Terrestrial animals live in a relatively high oxygen gaseous environment (>21% by weight) and use lungs for gas exchange. Aquatic animals have evolved diverse structures to utilize the oxygen that is dissolved in the water. However, oxygen is much scarcer in water (0.00001% by weight) making an adequate oxygen supply a bigger consideration for the aquatic animal. Also, to complicate matters even more, the effects of temperature on the fish and the availability of oxygen in the water operate in conflict. As water temperatures increase, the metabolism of the animal (and its oxygen demand) *increases*. However, as temperature increases the solubility of oxygen in the water *decreases,* meaning less is available just when the animal needs it most. Nature played a cruel joke on the aquaculturist (Timmons *et al.* 2002).

Another factor is the way that gills function. The water the fish lives in and the fluid of the animals' blood are separated by only a few cells. Whatever is in the water passes through the gills and into the fish's blood very readily. Also, the skin of most fish is very permeable making absorption of compounds passive and selective exclusion difficult or impossible. This issue is compounded by the fact that, through diffusion, anything added to a body of water rapidly disperses to all parts. If a noxious compound gets into the water it can spread throughout the system and quickly be absorbed into the aquacultured animal's body. No escape.

3.2 Ecological services provided by aquaculture production systems

As this discussion shows, aquatic animals are very much "captives" of their environment. As aquaculturists we do not so much manage the animals as much as we manage their environment. That is also largely the function of the different aquaculture systems—to manage the animals' environment. Not only must the environment be maintained to support life but in the case of aquaculture, it needs to be maintained in such a way as to support maximum growth rate, with maximum efficiency, and a minimum of waste.

As described earlier, many factors affect the survival and growth of aquatic animals. However, a few environmental variables are fundamental and a discussion of the ways that aquaculture systems control them is the unifying theme of this chapter and this book. Throughout the different chapters illustrations will be given on how the specific system being examined provides the cultured animal with the (1) proper temperature for growth, (2) sufficient oxygen to breathe, (3) removal of inevitable waste products, and in some cases (4) some or all of the animal's food needs.

3.3 Diversity of aquaculture animals

Terrestrial animal agriculture relies on relatively few species. In cattle, milk and meat production utilize one (*Bos taurus*) and (maybe) a second species

(*B. indicus*). In pigs, all commercial production is based on one species (*Sus domestica*). In poultry we have hundreds of varieties of chickens but they are all actually one species (*Gallus gallus*), and we also have the turkey (*Meleagris ocellata*). These animals are all warm-blooded and differ at the genus or class level. However, in aquaculture we raise well over 400 species (Duarte *et al.* 2009), all are cold blooded, and many differ at class or even phylum level. So what determines what their environmental needs and tolerances are, and what conditions must the chosen production system provide to raise that animal?

Basically, the environmental requirements of an animal are determined by its evolutionary adaptations for the environment it evolved in. In fish, we have broad categories that, based on the characteristics of their "natural" or natal environment, often tell us much about what they need, what they can tolerate, and even their nutritional requirements. These requirements and tolerances are often represented as a set of minima and maxima with a range in between. For some variables there will also be an optimum at which the animal operates most efficiently.

3.4 Temperature classifications of aquacultured animals

One way of classifying fish is based on water temperature (table 3.1). Fish are often characterized as coldwater, coolwater or warmwater species. Some descriptions add a fourth category of tropical species. The characteristics, requirements, and especially tolerances of the fish within these groups are largely controlled by enzyme functions and efficiencies. Many enzymes only operate within a limited temperature band, which, in the case of a poikilothermic animal, means that the animal also operates efficiently within a narrow temperature band (Somero & Hochachka 1971). In homeothermic animals such as cows, pigs, and chickens, they are able to burn calories to maintain their internal environment within a very narrow range, ensuring that the enzyme systems essential to many metabolic functions continue to work efficiently. In poikilotherms, the internal environmental temperature is controlled by the external environment, so it is important that the culture system provide that proper temperature.

Table 3.1 Generalized characteristics and trends among fishes characterized according to temperature range and salinity range.

Group	D.O. Requirement	Ammonia Tolerance	Protein Requirement	n-3 Fatty acids
Coldwater	>5 mg/L	Low	High	Required
Coolwater	>5 mg/L	Low	Moderate	Not required, but beneficial
Warmwater	>2 mg/L	Moderate	Moderate	Not required
Tropical	>1 mg/L	High	Low	Not required
Marine	Higher		Higher	Required
Freshwater	Lower		Lower	Not required

As stated earlier, the environment the species evolved to live in determined what temperature range it would be best adapted for. The conditions of that natal environment also affected other aspects of the animals' requirements and tolerances in terms of nutrition and water quality tolerances. Common generalities of fishes within the different temperature classifications are described below.

3.4.1 Coldwater species

Finfish and invertebrates whose thermal optimum for growth is below 20°C are classified as coldwater species. Examples of commercially important aquaculture species within this group include the marine Atlantic salmon (*Salmo salar*), the freshwater rainbow trout (*Oncorhynchus mykiss*), and the marine Pacific oyster (*Crassostrea gigas*). Rainbow trout are thought of as freshwater fish but are actually close relatives (same genus) of the Pacific salmons. Their optimum temperature for growth is about 10 to 16°C. They require relatively high oxygen levels (>5 mg/l) and tolerate only low levels of ammonia (<0.0125 mg/l unionized). This probably relates to their evolution in a coldwater environment where oxygen is abundant (the solubility of oxygen in water is inversely related to temperature) and accumulated nitrogenous wastes are relatively rare and of low toxicity (ammonia is less toxic at low temperatures and quickly flushed away in mountain streams). In the United States over 80% of commercial trout production occurs in the Hagarman Valley of Idaho (Hardy 1989) where huge volumes of groundwater break out of springs at approximately 15°C. Trout are very efficient converters of feed to flesh with about a 1:1 conversion ratio (Hardy 2002).

3.4.2 Coolwater species

Species whose optimum temperature is around 20°C are considered coolwater species. Currently there are fewer commercially important aquaculture species in this category. The striped bass (*Morone saxatilis*), yellow perch (*Perca flavescens*), and European perch (*Perca flaviatilis*) are examples. For the striped bass the optimal temperature is reported to be 15 to 17°C (Kohler 2000). However, much of the commercial production involves *Morone* hybrids whose optimum temperatures may be higher (25 to 30°C; Webster & Lim 2002) and would more properly be considered as warmwater fishes. The yellow perch and their cousin the European perch are coolwater species who are both being cultured commercially. It is estimated that approximately 226,000 kg/year of yellow perch were produced in 2005 (Hart *et al.* 2006). The European perch production in 2005 was estimated to be 315,000 kg (FAO 2007). The optimal temperature for yellow perch is 22 to 24°C with an upper lethal limit of 30°C (Hart *et al.* 2006).

3.4.3 Warmwater species

Many important aquaculture species are considered warmwater species, with an optimum temperature around 30°C. Among crustaceans, they would include the Pacific white shrimp (*Litopenaeus vannamei*), the tiger shrimp (*Penaeus mondon*), and the freshwater prawn (*Macrobrachium rosenbergii*). Among mollusks are the American oyster (*Crassostrea virginica*), Northern quahog (*Mercenaria mercenaria*), and blue mussel (*Mytilus edulis*). Among finfish we would include the common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), sea bass (*Dicentrachus labrax*), gilthead sea bream (*Sparus aurata*), and yellowtail (*Seriola quinqueradiata*).

Compared to coldwater species, warmwater species in general tend to have a greater tolerance for lower dissolved oxygen (DO) levels. This is logical as warmwater will hold less oxygen so the fish would be more likely to evolve mechanisms (mechanical and biochemical) to deal with low DO environments. They also tend to tolerate higher levels of un-ionized ammonia. Again, because of the dynamic equilibrium whereby higher temperature (and high pH) shift more total ammonia into the un-ionized form, warmwater species are more likely to need to evolve mechanisms to deal with high concentrations.

3.4.4 Tropical species

As stated earlier, some classifications add a fourth category. Tropical species would be those whose optimum temperature would be >30°C. You may also add a characteristic of having a minimal lethal temperature of ≤10 to 15°C. Examples would be tilapia, with an optimum temperature of 29 to 31°C (Popma & Masser 1999). To demonstrate the impact of temperatures, the growth rate of tilapia at 30°C is three times greater than at 22°C. However, growth is not the only variable that is affected. When tilapia are exposed to temperatures <18°C they handle poorly and get sick easily as their immunocompetence is severely compromised at temperatures below their optimal range. At temperatures of <10 to 12°C they normally die within a few days as enzyme systems cease to function. However, at temperatures >25°C, tilapia are very tolerant of handling low oxygen levels and high ammonia levels (Stickney 2000). The tilapia species preferred in aquaculture are native to the Middle East and Africa. In much of their home range tilapia have evolved to live in small water bodies that can shrink during the dry season and have low oxygen levels and poor water quality. Tolerance of these conditions was a strong selective pressure in their evolutionary history.

3.5 Temperature control in aquaculture systems

As stated earlier, temperature permeates all aspects of an aquacultured animal's growth, health, and even nutritional requirements. Different production systems

approach temperature control (or a lack of it) in different ways (reviewed in chapter 4). However, even *within* the aquaculture animals' acceptable temperature range, rapid changes can be stressful or even lethal. Why? Again, the animal cannot compensate and control its internal environment. Because of the high specific heat of water, compared to air, the aquatic environment tends to be a very stable environment. Under most natural conditions, aquatic animals would rarely be exposed to rapid temperature changes and have not developed mechanisms to allow them to deal with it. Aquatic animals can adapt to temperature changes within their range of tolerances, but only very slowly. A rule of thumb is that fish should only be lowered about 5°C per hour (Stickney 1979). Rapid changes represent stressful or even lethal conditions for the fish. Because fish cannot control their internal temperature, and the "operating range" of enzymes is normally very narrow, fish must actually induce (turn on) the production of new enzymes to be able to function at these new temperatures.

In some aquaculture systems, such as open ponds, water temperatures are controlled by ambient air temperatures and solar radiation. Most pond production occurs using warmwater animals in tropical or semi-tropical climates where water temperatures vary only a few degrees seasonally. However, even a 2 to 3°C seasonal variation can significantly impact production during the tropical winter and summer seasons. When warmwater fish are raised in temperate ponds, such as catfish production in the continental United States, fish growth may stop entirely for several months during the winter. An even more pronounced affect occurs when tropical animals such as tilapia or freshwater prawns are raised in temperate ponds. Water temperatures can reach the animal's thermal minimum by late fall and the animals will die if not harvested before temperatures drop too low (Tidwell & D'Abramo 2010). This also creates a need to overwinter broodstock indoors in heated tanks and requires that a hatchery and/or nursery be operated seasonally, increasing costs and the potential of missing an entire year of production should hatchery or nursery problems occur.

Some systems, such as trout raceways, often utilize groundwater resources. Water temperatures in these systems usually do not vary over 1 to 2°C season to season. In this case, we can't change the water temperature so we must choose a species that performs well at *that* given temperature. The majority of rainbow trout production in North America is conducted in this type of system and the optimum temperature range of the animal (10 to 15°C) closely matches the temperature of the groundwater, which breaks out of the ground as springs. While there are no heating costs to the water, there is conversely little flexibility in siting. The production system must be brought to the water resource and commercial scale springs (minimum water flow of >1,900 Lpm) can be difficult to find. That is why approximately 80% of the trout production in the United States is located along the Hagerman Valley of Idaho where there are many large springs (Hardy 1989).

The opposite extreme is found with the use of the recirculating aquaculture systems. Most of this type of production is conducted indoors and systems can be designed to operate at almost any temperature in almost any climate. This offers tremendous advantages in terms of what species will be raised and where. We

can raise a tropical species, such as tilapia, in far northerly latitudes or coldwater species, such as trout, in southerly latitudes. We can also site production near, or even in, urban settings with their large market potentials. However, energy costs are major considerations in these systems and the greater the temperature differential that must be maintained between outdoor temperatures and culture system temperatures, the more it will cost.

3.6 Providing oxygen in aquaculture systems

Oxygen is our second consideration. As discussed previously, compared to the atmosphere, when we move into an aquatic environment oxygen is much less abundant. While air is approximately 21% oxygen by weight, water, which is saturated with oxygen, contains <0.0005% oxygen by weight. To dissolve the oxygen in water it has to be squeezed in between the water molecules and there just isn't as much room there as there is in widely spread gas molecules.

3.6.1 Oxygen in open systems

In open systems, such as shellfish or sea cages, the production system relies on the natural environment's processes (primarily algal photosynthesis and diffusion) to provide the oxygen needed for the animals. The aquaculturist also relies on wind, currents, or tides to move the water and oxygen to and through the system. For those systems, proper siting is a major consideration.

3.6.2 Oxygen in semi-closed systems

In semi-closed systems, such as ponds, we rely on similar processes (photosynthesis and diffusion) to provide oxygen. However, in these smaller static water systems algal photosynthesis becomes much more important. In fact, on a calm day diffusion plays only a minor role. On a molecular scale, diffusion can move oxygen through the water column only relatively slowly. Supplied by photosynthesis and atmospheric diffusion, an area of saturation develops at the air/water interface, but oxygen does not efficiently move deeper down the water column. In pond systems, availability of oxygen is normally the first limiting factor in production intensification. The carrying capacity of an un-aerated pond is approximately 1,500 kg/ha. However, once supplemental aeration is provided, this figure increases threefold. Supplemental aeration is basically the use of mechanical devices to increase diffusion by increasing the contact between atmospheric oxygen and the water. This can be done either by injecting bubbles into the water column so that the oxygen inside the bubble can easily diffuse out into the water, or by pumping the water up into the air and breaking it into small droplets, which readily pickup atmospheric oxygen. The efficiencies of both types of aeration are greatly increased when they also provide circulation to move low oxygen

water into and highly oxygenated water out of the zone of the aerator. They also function to circulate the oxygenated water down through the water column.

3.6.3 Oxygen in closed systems

When we move into closed recycle systems (RAS) we now have to take over the entire oxygen demand of all of the components of the system. Just as with a pond, the cultured animals are not the only source of oxygen demand in this system. The bacteria colonizing the biofilter (see chapter 11) can also represent a significant demand. In a RAS, the water coming out of the biofilter should always be $\geq$2.0 mg/L (Timmons *et al.* 2002), ensuring that the oxygen demands of the nitrifying bacteria in the biofilter are being adequately met.

3.7 Waste control in aquaculture systems

3.7.1 Aquaculture produces less waste than terrestrial systems

The third function of all aquaculture systems is to remove waste products. All animals produce wastes and compared to terrestrial animals, aquatic animals produce relatively smaller amounts, for several reasons. One is the fact that they are poikilothermic. This means they burn no calories when maintaining an internal body temperature higher than the environmental temperature. The main reason a cattle farmer feeds his cows all winter, especially on the coldest days, is so they can metabolize the food to maintain their internal body temperature. Another reason aquatic animals produce fewer waste products is that most secrete ammonia passively, directly from the blood into the water through their gills. They don't have to expend any energy converting ammonia to less toxic forms such as urea (cows) or uric acid (chickens). Terrestrial animals also expend energy removing water from the wastes and storing those wastes for later excretion. These reduced metabolic costs represent significant energy savings and less wastes produced. Also, aquatic animals live in, what is for them, a basically weightless environment. Most can control buoyancy so they expend little or no energy fighting gravity. All of these energy savings mean it takes less food to grow an aquatic animal. For example, it takes 7 to 8 kg of feed to produce a kilogram of weight gain in cows, 3 to 4 kg of feed in swine, and 2 to 3 kg in poultry. However, for fish it takes only about 1.5 kg of feed. Because of this relatively efficient feed conversion, less feed in means less waste out. However, even in fish there is always some waste.

3.7.2 Ammonia production by aquacultured animals

One of the most important waste products produced by fish is the nitrogenous waste product ammonia. It is largely the breakdown product of protein

consumed in the feed. As stated earlier, it is primarily passively diffused through the gills. This is the classic "double-edged sword," though (and there are a lot them in aquaculture!). While passive diffusion saves energy compared to the other forms of nitrogenous waste excretion, it is the passive part that can create problems in production aquaculture. To be profitable, production aquaculture means we usually stock and feed fish at relatively high rates. Despite their efficiency relative to other farmed animals, approximately 87% of the nitrogen that fish take in as feed protein is released back into the water (Boyd 1979). This means that ammonia will accumulate in the water if not removed relatively rapidly and efficiently. As we pointed out earlier, aquatic animals readily take up compounds dissolved in the water through both their gills and skin, so toxic levels of ammonia can readily accumulate in the blood if allowed to build up in the environment. There must be some process to continually remove or detoxify the ammonia being excreted by the cultured animals into its surrounding.

3.7.3 Ammonia as a limiting factor in intensification

Different aquaculture production systems have several different methods to prevent the accumulation of ammonia produced by the culture animals. The rate and efficiency of the removal method is often the second limiting factor in system intensification (oxygen supply being first). In open systems, such as shellfish production, waste loads are low and natural diffusion can be sufficient to remove them. In other open system technologies, such as sea cages, natural water movement like tides or currents can augment diffusion to move the waste products away from the animals where they are processed or assimilated by natural processes (i.e., algal or bacterial). Even within semi-closed systems, raceways rely on a constant flow of new water to flush away the wastes. In raceways arranged in series and tiered in elevation, water dropping from one raceway to the next is reoxygenated with each drop, so the factor that limits the number of times it can be reused is the accumulation of ammonia. In semi-closed system ponds, mechanical aeration can provide for the oxygen budget of biomass densities beyond the current 5,000/kg/ha of many pond-based industries. It is the ability of the algal and bacterial populations in the ponds to process the ammonia loads that currently restrain additional intensification.

3.7.4 Ammonia control in closed systems—chemoautotrophic bacteria

As we move to recycle systems, the processes to remove (really convert) ammonia must be intensified. In most recycle systems this means pumping the water into specialized vessels where nitrifying bacteria are cultured at very high densities. Since these particular nitrifying bacteria grow best attached to a surface, these vessels are filled with specialized materials (such as pellets or strands), which have a lot of surface area for the bacteria to grow on and space for the water to

freely flow and deliver the ammonia to the bacteria. These vessels are known as biofilters because they use living organisms (bacteria) to "filter-out" the waste products. Their functionality and efficiency can often be improved by prefiltering with a mechanical filter. The removal of solids prevents clogging and reduces ammonia load and oxygen demand associated with the decomposition of solid wastes (such as feces and uneaten feed).

3.7.5 Ammonia control by heterotrophic bacteria

In recent years another type of closed recycle system has been in development. As opposed to more traditional recycle systems, which rely on autotrophic nitrifying bacteria confined in a biofilter, these systems are based on heterotrophic bacteria unconfined in the systems. These systems do not rely on highly efficient solids removal. In fact, significant amounts of solids are left in the system and suspended by heavy aeration. These suspend particles, known as bioflocs, not only support the growth of the heterotrophic organisms, which quickly and efficiently convert ammonia into bacterial biomass, but also can be consumed by the animal being cultured in the system and represent a source of nutrition and nutrient recycling.

3.8 Aquaculture systems as providers of natural foods

A fourth function provided by some systems is to also provide some or all of the food for the culture animals. In the culture of bivalves in open systems (chapter 5) essentially all of the food is provided by the culture environment. This is also true in reservoir ranching as described in chapter 8. In semi-closed system ponds there is a range of importance for the system being a provider of natural foods. For what are known as extensive ponds, the animals consume only natural foods and production is relatively low with a carrying capacity (CC) of approximately 150 kg/ha (table 3.2.) However, if we add organic or inorganic fertilizers, primary productivity is now increased. The culture animals still rely on natural foods but the CC is increased threefold to 500 kg/ha. If we

Table 3.2 Effect of fertilization, feeding, and aeration on estimated carrying capacity of a pond and the limiting factor to further intensification.

Management Input	Carry Capacity (kg/ha)	Limiting Factor
No inputs	150	Availability of natural foods
Organic fertilization	500	Availability of nutrients
Supplemental feeds	1,500	Low morning dissolved oxygen
Complete feeds with aeration	5,000	Ability to process nitrogen waste products

supplement the fertilized system with cereal grains for the animals to consume directly as "supplemental feed," CC is increased to 2,000 kg/ha (Tidwell *et al.* 1997). If we move to high-quality "complete" diets (diets containing all of the macro- and micro-nutrients needed by the species for growth and reproduction, CC can now be increased to >5,000 kg/ha. However, in aquaculture everything is interrelated. In pond systems, once we exceed 1,500 to 2,000 kg/ha, oxygen availability becomes limiting and above 4,000 to 5,000 kg/ha the ability to process nitrogenous waste products becomes limiting.

As you can see, while the basic functions of all aquaculture systems are quite similar, the path taken to accomplish these functions can be quite different. The theme of this book will be a more in-depth look at the major categories of aquaculture production systems with an explanation of how each one performs these basic functions or ecological services. Then we will examine some hybrid systems that combine positive aspects of different types of systems. Then we will look down the road to see what technologies and methodologies might await us to accomplish these tasks more rapidly, efficiently, or cost effectively in the future.

3.9 References

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